

The potential of water infrastructure to accommodate solar PV systems in Mediterranean islands



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ABSTRACT

Electricity production in Mediterranean islands currently depends heavily on imported fossil fuels. This strategy has several disadvantages and has been accused of hindering the islands' sustainable development. In the present research an integrated approach to increase solar photovoltaic (PV) systems' (SPVS) share in the energy mix of Mediterranean islands is presented, through installations on the available surface near existing water infrastructure. Accordingly, we have analyzed the potential of existing dams to accommodate SPVS on their downstream face as well as the option of SPVS over irrigation canals. We processed databases of water infrastructure in five big islands and developed a methodology to identify favorable locations. Using geographic information system (GIS) we processed the technical characteristics of each location and calculated the potential power capacity and the corresponding electricity production. Eleven dams were identified as "first-rate" locations with a total generating capacity of 63 MWp, producing 97 GW h of electricity annually, while additional 10 dams with less optimal conditions would add 30 MW of capacity and 33 GW h of annual production. We also identified an additional advantage of placing SPVS over irrigation canals, proposing additional 60 MWp capacity, namely the significant water savings through reduced evaporation.

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1. Introduction

Until recently, islands were regarded as locations where the development of variable renewable energy technologies (RETs) is more challenging than in mainland areas. Island grids are frequently isolated and cannot rely on power from the mainland grid. Moreover, RETs are often perceived to be less competitive than fossil fuel-based power generation. An important barrier raised is their intermittent output, that limits the range of use of the produced power.

1.1. Strategies for renewables' deployment in islands and island states

Renewable Energy Sources (RES) or a combination of renewables with storage and diesel generators are alternative options to reduce fossil fuel consumption and yield the lowest cost solution for generating electricity. At the same time RES' deployment would mitigate risks associated with oil price volatility. Provision of stable power and support of islands' energy autonomy

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(Sanseverino et al., 2014) is often based on increased penetration of RES and technologies of hybrid systems. Recently, the Spanish Canary Island El Hierro, with a population of 11,000 and energy consuming desalination plants, inaugurated a hybrid wind-hydro power plant (International Hydropower Association (IHA), 2015). This development has resulted to an almost 100% independence from fossil fuel imports. Cape Verde managed to increase the share of RES from 2.2% to 25% between 2009 and 2011. Moreover, according to the government plans supported by the West African Economic Community and the UN, the RES share will reach 100% by 2020, fully covering Cape Verde's electricity demand (United Nations, 2015).

1.2. Current status of electricity production in Mediterranean islands

The small islands of the Mediterranean Sea generally produce power based on diesel gensets that respond to the local electricity demand. In the larger islands, such as the ones analyzed in this study, a central power grid distributes the produced power. Similarly to the smaller ones, larger islands' electricity production also depends on fossil fuel imports of diesel, heavy oil and natural gas that impose significant costs and environmental burden.

The proposed approach studies the potential of existing water infrastructure to accommodate SPVS. Two different approaches have been examined, installations on the face of dams and SPVS covering irrigation canals. The integration of PV technology to existing infrastructure networks is expected to generate multiple efficiencies and cost-saving opportunities.

1.3. Energy and water interrelation in Mediterranean islands

Mediterranean islands have limited water resources and in many cases significant freshwater volumes need to be transported from the mainland. Such transport burdens the government budget, because the freshwater transport is inevitably subsidized (Gikas and Tchobanoglous, 2009) leading to a non-sustainable approach. This strategy is followed even in the larger islands of the Mediterranean Sea: Malta, Greece (Gikas and Angelakis, 2009), Italy (Cipollina et al., 2005) and Spain, because the continuous increases in water consumption cannot be covered by the limited local resources.

In many cases the water demand is partially covered through desalination and the exploitation of islands' groundwater resources. However, both desalination and groundwater pumping are energy-greedy processes that further increase the islands' energy needs. Thus, water provision operations may magnify islands' dependence on fossil fuel imports. The sensitive interrelationship between water and energy, justifies the perception that the Water-Energy Nexus is magnified in the context of islands (Grubert and Webber, 2015).

The close water-energy interrelationship has driven the present study to study possible efficiencies and opportunities between electricity production and water provision. Utilizing water infrastructure for SPVS installations is expected to create synergies with mutual gains for both fields.

1.4. Scope of the present work

In this work we present an alternative approach, in which solar photovoltaic systems (SPVS) are installed on available surface of existing water infrastructure such as dams and irrigation canals. This design allows the creation of synergies between the energy-producing SPVS and the water infrastructure. Addressing energy and water challenges in a comprehensive manner is a promising strategy in the islands' context, because it provides mutual benefits to both fields. It renders RETs deployment an economically attractive option and drives an integrated approach for the management of islands' resources towards sustainable development.

The developed methodology builds on our ongoing research on SPVS installations in developing countries (Kougias et al., 2016a), taking into consideration the particular characteristics of islands. Moreover, we present a methodology to assess the SPVS potential over existing irrigation canals. The aim is to minimize the current knowledge gap and trigger further research and pilot applications, by finding synergies and optimal sites for large-scale installations. In addition the proposed methodology can expand and be an element, both for the islands and Europe as a whole, to improve energy security.

2. Utilizing water infrastructure for solar PV system installations

2.1. SPVS installation on the face of existing dams

Dams generally offer a plane surface, on which PV module installations could be applicable. The proposed approach provides new opportunities for synergies and co-operation of the SPVS with

water reservoirs. In the case of hydropower dams the SPVSs are expected to decrease the pressure on hydroelectric stations for continuous water releases and energy production, securing water volumes for urban and irrigation uses. They will also support the complementary operation of the two RES, through hybrid operations (Kougias et al., 2016b) and increase the management options (Kougias et al., 2016c). In the case of non-powered water storage reservoirs, the produced solar electricity can be used for water treatment, pumping and other energy intensive operations (Patsialis et al., 2014).

SPVS installations on the face of dams of pumped-storage hydroelectric stations (PSHS) can further expand their role on island grids. Possible locations include the operational 500 MW Anapo station in Sicily as well as the planned 100 MW Ano Limnia PSHS in Crete, which will be hybridized with 90 MW of wind. Most of the islands in discussion are characterized by high elevation difference which is essential for developing new PSHS (Fitzgerald et al., 2012). PSHS can stabilize islands' energy grid and secure electricity availability (Kaldellis et al., 2010) and the SPVS installation on pumped-storage stations will increase the aggregated power capacity and support both functionalities (storage-production).

2.1.1. Applications in Japan and India

Local authorities in Hyogo prefecture, Japan announced their development plans to exploit the face and borrow pits of Kotani dam near the city of Himeji, with a capacity of almost 5 MWp as well as Heiso and Gongen dams (Fig. 1) near Kakogawa city, with a system capacity of 1.76 MWp (Kougias et al., 2016a). The original functionality of these dams was to provide drinking water to the nearby cities; the operation of the SPVS in 2014 has therefore extended their role to electricity production.

In a similar way the Indian authorities (Navi Mumbai Municipal Corporation, NMMC) decided to exploit Morbe dam on Dhavari river, in the western state of Maharashtra (Borowitzka, 2015). The project has already been approved by the state government's energy department. Morbe dam is a gravity, earth fill dam with a height of 59 m and a length of almost 3.5 km. Its large surface has a potential to develop a SPVS with a power capacity of 20 MWp, resulting in the world's largest solar PV project over a dam barrier. The total installation cost is estimated at €30 million (€1.5/Wp), while the generated annual revenue for the NMMC is estimated at €5.5 million.

2.2. SPVS installation over irrigation canals

Existing irrigation canals are an advantageous type of water infrastructure that offers a potential for SPVS installation (Fig. 2). India has been a pioneer country in the presented approach; in



Fig. 1. Solar PV transformation of Gongen dam, Japan.



Fig. 2. SPVS system over irrigation canals, India.

February 2014 U.N. Secretary General Ban Ki-Moon inaugurated a 10 MWp project of this kind in India. The system spans over 3.6 km of the Narmada irrigation canal in Vadodara, saves 16 hectares of land and it comprises 33,816 solar panels. The total project's cost was €16.4 million and was completed in six months (Acharya, 2015). During the inauguration, the central government announced it would promote similar projects in other parts of the country and sanctioned €32.2 million to construct 50 MWp of canal-top solar projects. Apart from the 50 MWp on canal tops, the Ministry of New and Renewable Energy (MNRE) in India launched a program for the development of additional 50 MWp of grid-connected SPVS on canal banks. Projects are under development in eight states and almost half of the overall 100 MWp power capacity is expected to be commissioned during 2016, while 26 MWp are planned to be commissioned in 2017 (Mercom Capital Group, 2016).

2.3. Advantages

Installing SPVS on the face of existing dams has technical advantages compared to ground mount or rooftop systems. Dams' construction involves the development of infrastructure that facilitates SPVS installation. Indicatively, dams offer easy access to the grid, since they are generally connected to operate their own machinery. Moreover, dams' road network provides easy access to the installation area and facilitates both the construction and maintenance of PV systems.

The benefits of the proposed systems result in savings of land and water for other uses. Since no acquisition of land is required, favorable economic terms are coupled with avoiding disputes among different land users.

2.3.1. Increased efficiency of solar panels

An additional advantage is the natural cooling of the SPVS. The performance of photovoltaic modules varies as a function of its operating temperature. The nominal power rating is at standard test conditions with a temperature of 25 °C. With increasing temperature the efficiency of a PV module gradually decreases and the change depends on the solar cell type and cell design. Typically a standard crystalline silicon module loses about 0.4–0.5% of its rated power per degree Celsius increase (Wysocki and Rappaport, 1960; Emery et al., 1996).

PV modules mounted on top of irrigation canals will have a lower operating temperature compared to ground mounted systems. Depending on the way how the modules are mounted over the canals, what temperature the water has and the actual water flow, the temperature difference between them and standard ground mounted modules can reach a few degree Celsius, resulting in a higher power output of the former. The actual power gain will depend on the local conditions and should be evaluated as a part of project development. The developers of the Narmada project (see Section 2.2) have estimated that the lower temperature will

increase solar panels' efficiency by as high as 7%, compared to ground mounted installations.

Long exposure testing (20 year) under various stresses showed that PV modules retain high-level performance even under extreme climate conditions (Skoczek et al., 2009). The imperfect encapsulation of early-year modules resulted in increased failure rates. However, the recent production techniques have addressed this issue. The available empirical data on floating SPVS (Lee et al., 2014) shows that both mounting materials and PV modules can operate above water with no significant influence on their lifetime or durability.

2.3.2. Irrigation water savings

Covering irrigation canals with PV panels would save water due to the reduction of water evaporation. Evaporation rates from flowing channels may vary and according to the literature can take values as high as 5–20 mm/day (Fulford and Sturm, 1984). Covering the canals with a SPVS is expected to significantly limit evaporation. Estimations focusing on the Mediterranean region show large variations of daily potential evaporation from 2 mm/day during typical Mediterranean wet winter to 7 mm/day during the dry summer (Vardavas et al., 1997). Naturally these figures vary between west and east (Romanou et al., 2010), but generally have average daily values that exceed 3.5 mm (1277.5 mm annually). We assumed that canals coverage will reduce the evaporation by $\approx 1/3$. This is equal to annual water savings of 440 mm (34.4%), compared to non-covered canals, which is a more conservative figure than values found in the literature. Indeed, the effect of various shading materials on the evaporation rate in the Mediterranean climate of south-east Spain was recently investigated (Martínez Alvarez et al., 2006) and the results indicated that shading induced a significant decrease of the daily evaporation rate, ranging from 50% to 80%.

The exact amount of savings depends on several parameters such as how the modules are mounted, water temperature and flow rate, as well as the irradiance and air temperature at each location. As the actual water saving depends on the local conditions it should be evaluated as a part of project development.

2.3.3. Combination with civil works

The presented approach can be combined with riverbed regulation civil works. This has also been the case in the project in India (Section 2.2), where the canal slopes were stabilized and the river bank was regulated to mitigate erosion. In that way, the overall investment has multiple environmental conservation benefits, because it secures the unobstructed flow of water in the canal and even improves flood mitigation infrastructure.

2.4. Opportunities for Mediterranean islands' energy autarky

The present research focuses on large Mediterranean islands due to their current dependence on importing fossil fuels, that imposes barriers on their economic development. A transition from imported fuels towards utilization of local RES could create opportunities for competitive electricity production.

Our analysis has focused on the five large islands depicted in Fig. 3 and aims to assess alternative paths for the installation of SPVS. The selected islands have an excellent solar electricity potential, among the highest in Europe (Šuri et al., 2007). The increased electricity demand in the touristic period (May–September) is positively correlated with the seasonal energy output of SPVS.

The unprecedented price decrease in RES technologies offers an opportunity to redefine islands' energy strategies and develop policies that deliver reliable electricity in a sustainable manner. The Islands Sustainable Energy Action Plans of Europe (ISEAPs) (European Commission, 2010) have projected ambitious capacity

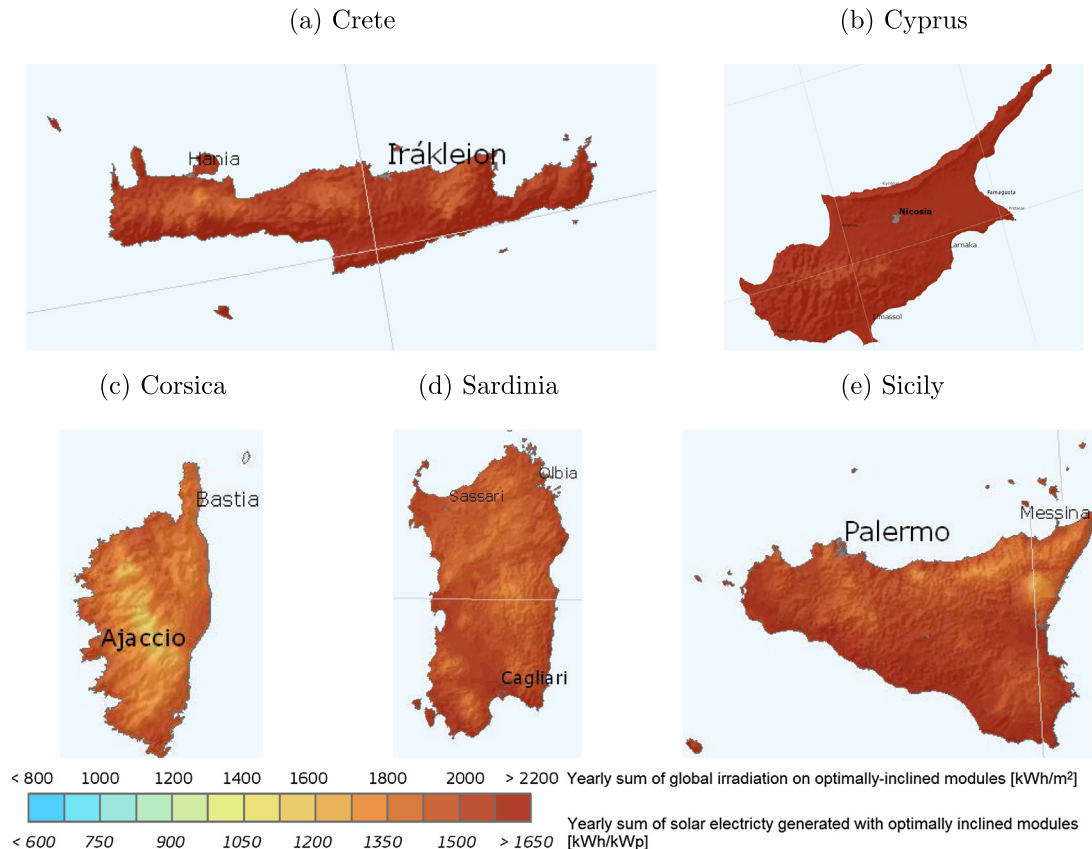


Fig. 3. Global irradiation & solar electricity generation by a 1 kWp system in the studied islands. Source: [Institute for Energy & Transport DG-JRC](#).

expansion targets for PV, up to 2020. However, the implementation of these plans lags behind. Besides, the diffusion of RES is often not just the best choice in terms of sustainable development. For most parts of the world it can also be a primary economical choice (Szabó et al., 2015).

2.5. Challenges

Islands face challenges related to several environmental and socioeconomic aspects. They are particularly vulnerable to climate change impacts (International Renewable Energy Agency (IRENA), 2014, 2015). Given their geographic characteristics they are clearly exposed to increasing natural hazards such as eroding coastlines, soil erosion, extreme weather conditions, droughts and floods. This favors public knowledge on climate issues, limits opposition against RETs and drives political agreements for RETs' supporting mechanisms. For this reason several islands have been pioneers for RET deployment, setting ambitious goals that even reach 100% dependence on renewable electricity (Praene et al., 2012; House of Representatives State of Hawaii, 2015).

Mediterranean islands are popular tourist destinations and attract several times more tourists than the permanent population. Thus, the electricity peak demand during the touristic period is significantly higher than winter demand. To date, this particularity has been addressed by excess over-sizing of the fossil-fuel capacities, most of which remain idle for long periods. Requirements associated with the maintenance of these capacities and transport of the equipment to islands, further increase the cost of energy production.

Land use in islands is a sensitive issue, because the available land is limited and the influx of tourists magnifies the challenge.

Accordingly the land has a particularly high value. Therefore, it is important to design strategies that support the efficient use of land and resources for RETs system deployment. This is further supported by the fact that land use intensity is often regarded as a proxy for other environmental impacts (Turney and Fthenakis, 2011).

2.5.1. Technical challenges of canal-top SPVS

SPVS installed over irrigation canals might have a higher cost compared to typical installations. The additional cost of civil works is due to the fact that PV panels need to be installed on steel scaffolding. The structures are mounted on the two sides of the canals and therefore need to be stronger than typical installations on land, thus adding more cost. There are also some questions regarding the maintenance cost of such projects, mainly due to the more difficult access. This can be further supported considering that canals themselves need maintenance from time to time for e.g. removal of debris and plant residues.

The particularity of canal-top SPVS imposes some technical challenges. Energy transport from small PV systems over a long distance may be more challenging than is usual. It may also involve an additional cost due to the need of longer cables. Moreover, modules need to be aligned in a uniform way, therefore the presented approach doesn't offer the flexibility to optimally orientate the SPVS. Generally it is expected to be difficult to achieve the same electricity production over a canal which might be curvaceous with changes in its direction. Since irrigation canals -as a rule- run parallel to farmlands, they have long straight parts. Utilizing parts of the long sections that have near optimal orientation for SPVS installation can be a strategy to maximize the energy output. In the tropical zone nearly horizontal PV systems could compensate for non-ideal azimuthal orientation.

3. Analysis

In this work the authors examined the possibility of the presented alternative options for SPVS installations to be implemented in the Mediterranean islands. The selection of exclusively water infrastructure has been based on the fact that water scarcity is a common issue in these islands (Viola et al., 2014) and is related to energy sufficiency.

The estimation of the output of the analyzed PV systems, has been performed using the web-based tool PVGIS (Institute for Energy & Transport DG-JRC), developed in the authors' Institute. The estimates are based on solar radiation data from the Satellite Application Facility on Climate Monitoring (CMSAF). The methodology to process this data has been described in (Huld et al., 2012). The estimated combined PV system losses are different for each location and range between 23.5% and 26.5%. Using local ambient temperature data, the main losses due to temperature are estimated (≈ 9 –12%), while losses due to angular reflectance effects represent ≈ 2.5 –2.7%. Cable, inverter and other losses are assumed to contribute an additional uniform percentage of 14% (Institute for Energy & Transport DG-JRC).

3.1. SPVS installation on dams in Mediterranean islands

The authors have developed a methodology that supports the selection of the first-rate dams for SPVS installations presented in Kougias et al. (2016a). For the needs of the present research information on existing dams in selected islands were collected. Their parameters were analyzed and their geometrical characteristics such as height, slope, length of crest along with hydrological information were processed. Orientation and tilt of dams were also analyzed. They are important selection criteria that define the SPVSs' performance, since PV modules are installed parallel to the dams' downstream face.

In total 39 dams in Crete, Cyprus, Corsica, Sardinia and Sicily were identified. These dams provide water storage for drinking water, irrigation or hydroelectric energy production. They also provide a flat zone for SPVS installation, whose area was estimated based on dams' geometrical parameters (crest length, height) and GIS-based measurements (geo-referenced data, image interpretation).

The available area for SPVS installation was estimated as equal to the orthographic projection of the dam, as a trapezoid. For each dam all natural or artificial obstacles that hinder PV module installation were considered. SPVS can be mounted on the face of each dam excluding spillways, gateways and any machinery and excluding such equipment resulted to the available dams' area. The installed PV system would ideally impose minimum modifications on dams surface. Accordingly, PV modules will be installed parallel to the dam's surface, to minimize obstruction and additional weight. We assumed that the required distance between modules to provide walkways for maintenance and avoid shading, requires 20% of the total area.

3.1.1. First-rate dams

Eleven of the analyzed dams have been identified as first-rate locations (Fig. 4), because they offer an almost optimal orientation and tilt for SPVS installation (see Table 1). The table presents the net estimated area and includes the aforementioned 20% buffer zone. Their technical characteristics, included in Table 1, show that they generally have a south orientation and a near-optimal tilt, with values around 30°. Considering that the optimal SPVS tilt for the geographic latitude of Mediterranean islands ranges between 30° and 35°, it appears that these dams are excellent locations for SPVS. Naturally, ground mounted systems can generally

be optimally installed in terms of orientation and tilt. In the case of dams there is only limited flexibility, since the installation surface is already in place. Still, the identified 1st-rate dams utilize significant share (Table 1, estimated solar electricity output - actual) of the available potential (Table 1, estimated solar electricity output - optimal). This is indicated by the high values of the "share" column in Table 1, that shows the ratio of the solar electricity between an actual system installed on these dams divided by the output of an optimally installed ground mounted SPVS at the same location.

The utilization of the 1st-rate dams would contribute an additional capacity of almost 63 MWp, producing 97 GW h of clean energy, annually. 47 GW h of this is located in Sicily and has the potential to cover 7% of the annual consumption (670 GW h). The available 26.8 MWp in Cyprus offer an opportunity to significantly increase the installed PV capacity from the current 73.4 MWp to more than 100 MWp. 96 MWp of PV systems are already providing electricity to Crete, therefore the additional 3.2 MWp will have a limited impact. Still, Bramianos dam offers optimal conditions and 100% utilization of the available solar potential.

In specific cases like the one in Fig. 4g, the dam is located next to a waste-water treatment station and the presented approach can have an even bigger impact. SPVS can provide energy for waste-water treatment or combine its output with electricity produced by biosolids/biogases.

3.1.2. Second-rate dams

Apart from the 1st-rate locations, our analysis distinguished 10 more dams that favor PV systems' installation (Table 2). These dams have a non-optimal orientation and consequently don't utilize the full solar potential of their location. However, the Mediterranean region offers a solar electricity potential among the highest in Europe with values up to 1750 kW h/kWp (Šúri et al., 2007). Therefore, even dams with non-optimal inclination can still become advantageous locations. This is the case when dams have a large, flat and inclined surface that offers the potential to accommodate solar PV systems without obstructions and produce renewable energy in an efficient manner. Moreover, their orientation and tilt, although non-optimal, still utilizes a large proportion of the local solar potential, with an average value equal to 76.2% (Table 2). The transformation of these dams would contribute to an additional solar PV power capacity of almost 30 MW, that would annually produce more than 33 GW h of clean energy.

3.1.3. Extending the SPVS installation in the dam's surrounding area

The installed solar PV capacity can be increased by module installation in the area near the dam's toe (Kougias et al., 2016a). The applicability of this option is case-dependent and not related to the dam's classification according to the present methodology. Property or environmental issues are not expected to occur, since such areas are supervised by the reservoir operator authority.

3.2. Irrigation canals for SPVS installation in Mediterranean islands

The analysis of the irrigation network and canals on the selected islands was organized in the following steps: Initially we located the canal network and performed an initial screening. In some cases the irrigation network is a pipeline system and obviously closed conduit systems cannot be utilized for SPVS installations. That appeared to be the case in Corsica and Crete, where none of the canals in our databases was suitable to accommodate SPVS.

When crossing inhabited areas, irrigation canals are often buried underground as conduit systems and run underneath the settlement. Eventually they emerge and outflow into a canal at the outskirts of the settlement. Our analysis has excluded such sections. Often canals constitute an important nesting site for several



Fig. 4. Dams in Mediterranean islands rated as first-rate locations for SPVS installations.

aquatic bird species and have slowly transformed into an excellent natural habitat over the passing decades, therefore, our analysis also excluded canal sections in environmentally protected areas. Canals intersect with the river and road networks and in such places a bridge is typically built over the canal. Due to the shading effect of the bridge, such sections have been excluded from our analysis. Table 3 includes the selected canals, their technical characteristics and potential energy output. In total 15 canals were distinguished: 11 in Sardinia, 3 in Sicily and 1 in Cyprus.

The net length and the width of the canals were estimated using GIS. Some of the selected canals in Sardinia do not have a constant width. In such cases we assumed that the canals' width changes linearly among the different cross-sections and we calculated their area accordingly. In order to estimate the total module area we have considered an inclination for each SPVS that maximizes the output. The required distance between the PV racks to avoid shading was also taken into account and was estimated similarly to typical ground mounted systems.

Table 1

Technical characteristics of the 1st-rate dams' locations for SPVS installations.

Dam	Island	Main use	Net estimated area [m²]	Height [m]	Azimuth [0–360°]	Tilt [0–90°]
Rubino	Sicily	Irrigation	8900	39	198	25
Garcia	Sicily	Irrigation	36,000	45	165	27
Trinita	Sicily	Irrigation	6000	29	202	22
Nicoletti	Sicily	Irrigation	60,100	48	110	26
Villarosa	Sicily	Drinking water	40,200	40	242	18
Disueri	Sicily	Irrigation	55,300	74	220	30
S. Rosalia	Sicily	Irrigation	12,700	54	160	27
Bramianos	Crete	Hydropower	21,700	63	174	29
Yermasoyia	Cyprus	Hydropower	17,900	49	198	37
Asprokremos	Cyprus	Hydropower	50,400	56	205	20
Kouris	Cyprus	Hydropower	110,500	113	185	28
Est.solar el. optimal [kW h/kWp]			Est.solar el. actual [kW h/kWp]	Share p./opt. [%]	Power capac. [kWp]	Est. el. output [MW h/yr]
Rubino	Sicily	1410	1400	99.3	1335	1869
Garcia	Sicily	1480	1410	95.3	5400	7614
Trinita	Sicily	1480	1440	97.3	900	1296
Nicoletti	Sicily	1510	1170	77.5	9015	12,260
Villarosa	Sicily	1530	1400	91.5	6030	8442
Disueri	Sicily	1570	1510	96.2	8295	12,525
S. Rosalia	Sicily	1430	1420	99.3	1905	2705
Bramianos	Crete	1590	1590	100	3255	5175
Yermasoyia	Cyprus	1690	1660	98.2	2685	4457
Asprokremos	Cyprus	1700	1660	97.6	7560	12,550
Kouris	Cyprus	1700	1700	100.0	16,575	28,178
Total					62,955	97,072

Table 2

Technical characteristics of the 2nd-rate dams' locations for SPVS installations.

Dam	Island	Main use	Net estimated area [m ²]	Height [m]	Azimuth [0–360°]	Tilt [0–90°]
Alesani	Corsica	Irrigation	12,902	65	95	41
Cuga	Sardinia	Irrigation	11,131	53	285	39
Alto Temo	Sardinia	Irrigation	3220	58	158	64
Rio Olai	Sardinia	Drinking water	16,007	54	262	47
Fonni	Sardinia	Drinking water	3930	30	70	39
Cantoniera	Sardinia	Drinking water	37,108	100	235	76
Poma	Sicily	Irrigation	29,695	53	270	26
Scanzano	Sicily	Drinking water	32,557	40	72	25
Ancipa	Sicily	Hydro	15,672	104	185	85
Evretou	Cyprus	Hydro	37,415	70	300	26
Est.solar el. optimal [kW h/kWp]			Est.solar el. actual [kW h/kWp]	Share p./opt. [%]	Power capac. [kWp]	Est. el. output [MW h/yr]
Alesani	Corsica	1340	1030	76.9	1935	1993
Cuga	Sardinia	1410	1030	73.0	1670	1720
Alto Temo	Sardinia	1330	1170	88.0	483	565
Rio Olai	Sardinia	1410	1130	80.1	2401	2713
Fonni	Sardinia	1370	939	68.5	589	554
Cantoniera	Sardinia	1450	1020	70.3	5566	5678
Poma	Sicily	1510	1250	82.8	4454	5568
Scanzano	Sicily	1370	1110	81.0	4883	5421
Ancipa	Sicily	1410	908	64.4	2351	2135
Evretou	Cyprus	1610	1230	76.4	5612	6903
Total					29,945	33,248

3.2.1. Power capacity and electricity output of the canal-top SPVSs

Eventually the area available for SPVS was estimated and it is illustrated in Table 3. The degree of utilization of existing canals for SPVS installation is a techno-economic issue that exceeds the scope of the present research. The selection of locations for SPVS installation over the canals is also dependent on their proximity to the grid, the energy demand and the energy intensity of productive activities. An entire transformation of all irrigation canals to accommodate PV systems might not be feasible. But even then, a gradual implementation in several phases is advisable, in order to monitor the systems' performance. Accordingly, the present research studied a utilization rate of 30% for the canals, assuming that in a first phase the most advantageous part of the available potential will be utilized.

The expected contribution of the proposed approach is presented in Table 3. Utilization 30% of the available area on the ana-

lyzed canals can contribute almost 60 MWp of additional power capacity (more than 52.5 MWp in Sardinia, 1.5 MWp in Sicily and 4 MWp in Cyprus). These capacities are expected to contribute almost 90 GW h of clean energy, on an annual basis. Almost 80 GW h of this power is based in Sardinia and given that the overall electricity consumption is approximately 344 GW h, the proposed scheme could cover almost 1/4 of the demand. For Cyprus the annual output of ≈ 7 GW h represents a 10% increase on the total ground mount PV production (76.5 GW h at the end of 2015).

3.2.2. Water savings of the canal-top SPVSs

In order to estimate water savings, we adopted from the bibliography conservative figures for evaporation and savings due to shading. We made this decision based on the fact that irrigation canals do not have a steady water flow. Therefore, evaporation will vary significantly, especially if irrigation is intermittent. Our

Table 3

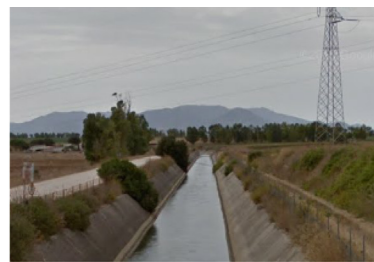
Technical characteristics of the selected canals for SPVS installations.

Nearby city	Island	Length [m]	Width [m]	Available area [m ²]	Utilized area [m ²]
Solarussa	Sardinia	27,703	4.5	125,000	37,500
Zerfaliu	Sardinia	36,371	7.3	266,000	80,000
Tanca Marchese	Sardinia	5380	9.0	48,500	15,000
Rio Mogoro	Sardinia	7307	13.3	97,000	29,000
Rio Putzu Manu	Sardinia	5716	24.7	140,000	42,000
Perfugas	Sardinia	5779	27.0	156,000	47,000
S. Lucia	Sardinia	3859	4.1	16,000	4800
Olbia	Sardinia	1888	21.0	40,000	12,000
Loc. Villasanta	Sardinia	6052	9.7	58,000	17,500
Monastir	Sardinia	25,226	5.3	135,000	40,500
Guamaggiore	Sardinia	13,691	6.3	87,000	26,000
can. Cavanzzini	Sicily	8980	2.6	23,500	7000
S. Leonardo	Sicily	1759	4.0	7000	2100
Agnone	Sicily	1049	4.0	4200	1250
Paphos	Cyprus	7062	13	92,000	27,500
		Est.solar el. optimal [kW h/kWp]	Power capac. [kWp]	Est. el. output [MW h/yr]	Est. water saving [m ³]
Solarussa	Sardinia	1510	5625	8494	16,500
Zerfaliu	Sardinia	1500	12,000	18,000	35,000
Tanca Marchese	Sardinia	1530	2250	3443	6300
Rio Mogoro	Sardinia	1520	4350	6612	13,000
Rio Putzu Manu	Sardinia	1490	6300	9387	18,500
Perfugas	Sardinia	1460	7050	10,293	20,500
S. Lucia	Sardinia	1485	720	1069	2100
Olbia	Sardinia	1500	1800	2700	5200
Loc. Villasanta	Sardinia	1520	2625	3990	7700
Monastir	Sardinia	1590	6075	9659	17,700
Guamaggiore	Sardinia	1520	3900	5928	11,500
can. Cavanzzini	Sicily	1590	1050	1670	3000
S. Leonardo	Sicily	1580	315	500	900
Agnone	Sicily	1600	188	300	500
Paphos	Cyprus	1720	4125	7100	12,000
Total			58,373	89,137	170,400

(a) Tanca Marchese canal



(b) Loc. Villasanta canal

**Fig. 5.** Canals for SPVS installations in Sardinia, Italy.

estimations generally expect 3000 m³ of water savings per MWp of SPVS. Considering water scarcity issues in the Mediterranean islands and the particularly high value of water in islands, it appears that the proposed strategy can be an important step towards the sustainable development of Mediterranean islands.

The integration to the landscape, the local architecture and the aesthetics is also an important issue, especially for such touristic destinations. In Fig. 5 two of the analyzed canals are illustrated. We believe that the suggested approach could be part of an integrated development plan in these islands. Thus, installation of SPVS over canals would aim to improve the aesthetics of the - often neglected- areas around the canals.

4. Conclusions

Although Mediterranean islands have a unique wealth of untapped solar potential, their current power production portfolios

are characterized by delivering costly and unsustainable electricity to consumers. This is due to the fact that islands still rely on one of the most expensive resources i.e. heavy oil, which nowadays is hardly utilized in European mainland. The main reason for that is logistic: fossil fuel resources can be transported and stored in big quantities. However, the new challenges to provide citizens with sustainable, affordable and clean energy, question the present energy provision strategy and call for imminent changes.

The proposed approach has multiple positive economic and environmental attributes offering a win-win situation for islands' sustainability: it provides energy from indigenous sources, relies on existing infrastructure, does not affect nature protected areas and aims to develop mostly industrial or intensively cultivated agricultural lands. The developed methodology identified more than 90 MWp of SPVS on dams and almost 60 MWp on canals that could quickly ramp up in the islands' power generation portfolio and would not conflict with other land uses. At the same time

the proposed industrial-scale SPVS could reduce both cost and time required for a technological shift, providing tangible RES options into the islands' energy mix.

In the case of canals it has also the potential to secure $\approx 170,000 \text{ m}^3$ of water, annually. Apart from its environmental importance, this volume has a significant economic value: it can further support the agricultural sector, provide urban water services and reduce the operation cost of desalination plants and groundwater pumps.

The economic analysis of the electricity-water costs involved exceeds the scope of the present study. Each of the selected islands has a different size, status and needs. Moreover, the islands are under different jurisdiction and adopt different policies, making such an analysis complicated. The objective of the present study is to develop and present a methodology for estimating the existing solar potential in water infrastructure. The authors intend to extend to the economic aspect in their future work.

It is expected that a supportive policy environment could effectively promote the development of the proposed installations. In that way a framework defining such an approach would secure water infrastructure operation, promoting at the same time increased SPVS penetration in the energy market. Since the selected projects are typically located in less developed rural and industrial areas of the islands, they are more likely to attract funding from national, EU or multinational regional development funding institutions.

Disclaimer

The views expressed in this paper are purely those of the authors and may not in any circumstances be regarded as statements of an official position of the European Commission.

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